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EXHIBIT C

Introduction to Ceramics

Second Edition

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Preface to the Second Edition

During the fifteen years which have passed since the first edition wa published, the approach described has been widely accepted and prac ticed. However, the advances made in understanding and controlling an developing new ceramic processes and products have required substanti modifications in the text and the introduction of a considerable amount c new material.

In particular, new and deeper understanding of the structure c noncrystalline solids and the characteristics of structural imperfection new insight into the nature of surfaces and interfaces, recognition c spinodal decomposition as a viable alternative to classical nucleatio recognition of the widespread occurrence of phase separation, develo ment of glass-ceramics, clearer understanding of some of the nuances c sintering phenomena, development of scanning electron microscope an transmission electron microscope techniques for the observation c microstructure, a better understanding of fracture and thermal stresse and a myriad of developments relative to electrical, dielectric, an magnetic ceramics have been included. The breadth and importance c these advances has made a single author text beyond any individual competence.

The necessary expansion of material related to physical ceramics, an the recent availability of excellent texts aimed at processing and manufa turing methods [F. N. Norton, *Fine Ceramics*, McGraw-Hill, New Yo (1970); F. H. Norton, *Refractories*, McGraw-Hill, New York (1961); F. I Norton, *Elements of Ceramics*, second ed., Addison Wesley Publ. C (1974); F. V. Tooley, ed., *Handbook of Glass Manufacture*, 2 Vol Ogden Publ. Co. (1951); A. Davidson, ed., *Handbook of Precisi*

different from that of the matrix is the most satisfactory; sodium and calcium fluoride are very commonly used, as indicated in Table 13.5.

Frequently the translucency of single-phase oxide ceramics is cited as an indication of their overall quality. This index of quality works reasonably well because the pore size is similar in different bodies and the translucency depends almost exclusively on the pore concentration. (Strength and other properties are closely related to the porosity.) In aluminum oxide, for example, the index of refraction of the solid is relatively high ($n_D = 1.8$), whereas the index of refraction of the pore phase is near unity, giving a relative index of 1.8, which is very high. The pore size for these bodies usually corresponds to the original particle size of the starting material (frequently 0.5 to 2 microns) and is nearly the wavelength of the incident radiation so that the scattering is a maximum. Consequently, as indicated in Fig. 13.18, the transmission is found to be reduced to 0.01% by the addition of about 3% porosity. Even when the porosity is reduced to a value of 0.3%, the transmission is still only about 10% that of a completely dense sample. That is, for high-density single-phase ceramics containing fine porosity the translucency is a sensitive measure of the residual porosity and consequently a good indication of the quality of the ware.

The aesthetic value of many porcelain compositions is judged by the translucency. This together with good mechanical properties is the basis for compositions such as bone china and hard porcelain having high translucency. For porcelain bodies the phases present are normally a glass having an index of refraction of approximately 1.5, mullite ($n_D = 1.64$), and quartz ($n_D = 1.55$). As discussed in Chapter 11, in the normal microstructure of dense vitrified porcelain the mullite phase appears as fine needle crystals in a glassy matrix with larger quartz crystals which are undissolved or partially dissolved (see Fig. 11.11). Consequently, although the particle size of the mullite is in the micron range, the particle size of the quartz is much larger. Both because of the difference in particle size and because of the greater difference in the index of refraction, the mullite phase is the main contributor to scattering and decreased translucency in porcelain bodies. The primary method by which the translucency can be increased is to increase the glass content, decreasing the amount of mullite present. This can be accomplished, for example, by increasing the ratio of feldspar to clay, as discussed in Chapters 7 and 11. Frit porcelains and compositions, such as dental porcelains having a high feldspar content, are given high translucency by increasing the amount of glass at the expense of mullite development. For other purposes, however, this is deleterious, since it lowers the strength which the presence of mullite adds to the body.

In the same way that porosity greatly decreases the translucency of single-phase alumina, the presence of voids ($n_D = 1$) is deleterious in

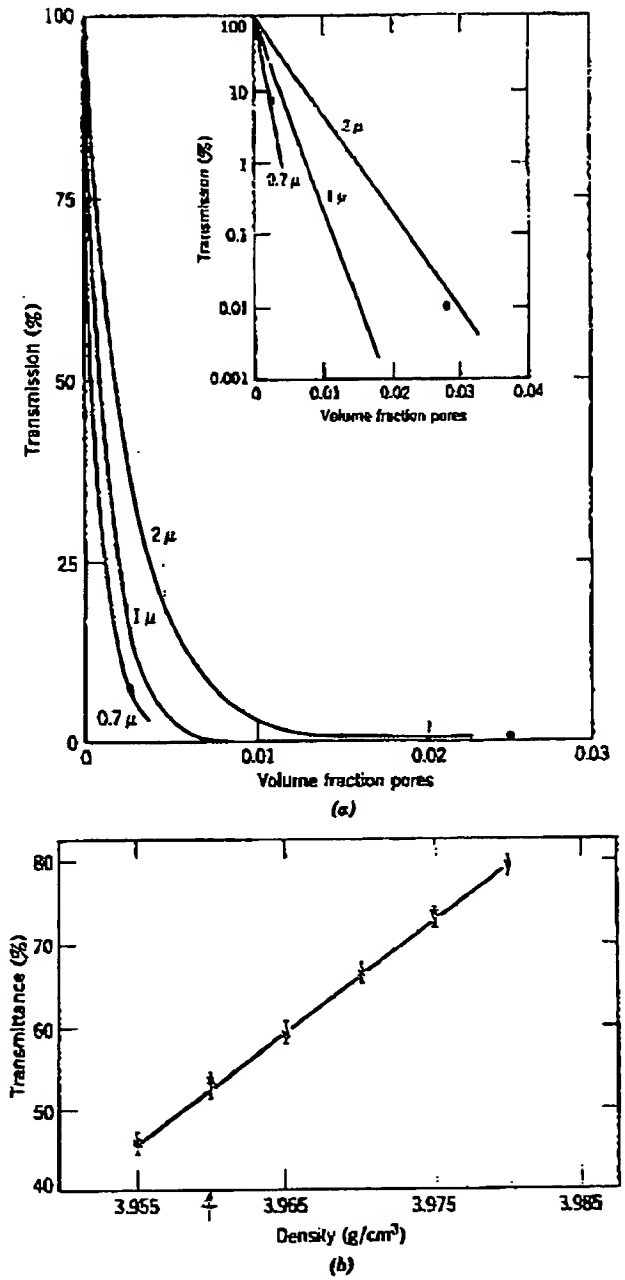

Fig. 13.18. (*a*) Transmission of polycrystalline alumina containing small amounts of residu porosity (equivalent thickness 0.5 mm). From D. W. Lee and W. D. Kingery, *J. Am. Ceram Soc.*, 43, 594 (1960). (*b*) Effect of density on transmittance at 4.5 microns of Al_2O_3, grain siz 27 ± 3 microns, thickness 0.5 mm, surface finish $< 5\ \mu$ in. From H. Grimm et al., *Bull. An Ceram. Soc.*, 50, 962 (1971).